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DETERMINATION OF POWER OUTPUT AND IMPACT ON THE RHEOLOGICAL PARAMETERS OF RAW MATERIALS DURING ROLLING

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ABSTRACT

The paper presents mathematical modelling of determining the power output over the rolling materials in the gap rotating rollers taking into account the rheological parameters of the final product. Determination of these parameters will reduce energy consumption, increase efficiency and reduce loss of material during production. This solution, suggested in the article, allows determination of the overall quality of the rolled product layer. Analysis of experimental results revealed that the main features of the machine provide the necessary stable shape products and provide good rheological parameters of these products. Rheological testing indicators allow for a rational approach to a decision to operate a rolling process. At the same time they improve quality control methods and will have an impact on the design parameters of rollers and modes of chambers. The proposed method not only allows obtaining a predetermined pressure, but also allows defining the optimal shape of the gap, wherein the pressure gradient is constant.

Introduction

High demands concerning the quality of formation determine the difficulty of choosing an effective technological process and equipment. Creating conditions for rolling the agricultural raw material, applying the effective mechanical methods of impact, elimination of unproductive labour, i.e. creation of resource-saving technologies of formation is one of important tasks for the development and improvement of technological processes in molding machines with roller working bodies. However, in the modern period of market relations, the process of forming the component has become a serious obstacle to the creation of new opportunities of technological processes. Therefore, we lead engineering and scientific research for improving the technology of forming the raw material, development of new machines and principles of operation that enhance their efficiency and productivity.

For the accelerated development of production of flour products in the confectionery and bakery industries it is necessary to direct the scientific and technical potential of

Ukraine to efficiently use domestic raw materials of each region and at the same time to guide the modernization, development and implementation of energy – saving waste – free technologies. This approach will allow, on the basis of the highly effective technique, introduction of a new generation food products. A roller machine is the simplest and most reliable existing equipment that is used for the production of different varieties of bakery and confectionery flour products. Rolls are widely used in various sectors of the food industry. They are used in flour milling, confectionery, pastry, bakery industry.

To improve equipment roller working bodies and their implementation, it was necessary to develop a science – based method of calculating operating parameters occurring in these machines. At the same time, it is necessary to improve the process in the working chamber on the basis of rational design parameters. Great development in the study of the flow of non-Newtonian fluids in rotating rollers slot has been included in the hydrodynamic theory in the processing of the masses of food by scientists Go Lunin, I Machihin, Sa Machihin, Virginia Aretha, Ava Panfilov, etc. They have found that the dough refers to pseudoplastic bodies, which are described by the Ostwald power law (Андреев, 1975, Арет, 1969). N.V. Zaitsev, A.T. Lisovenko explored the working rollers during rolling, injection and rolling-baking test (Стадник and Науков, 2013). They considered the nature of the movement of dough in the roll gap and the terms of tightening the ball-shaped piece. The problems concerning the flow test in the gap between the kneading cylindrical displacement body and the working chamber are emphasized by (Зайцев and Пеленко, 2012)

The basic data needed to calculate the roll of the working bodies is the torque, absorbed power and force of the impact rollers and dough during operation. These values by different researchers were determined by the techniques of (Андреев, 1975), based on the regularities of plastic or elastic deformation of the material between the rollers. The study was based on the hydrodynamic theory of rolling and similarity theory.

In the works with yeast wheat and pasta component, the above mentioned researchers do not fully draw attention to the influence of the gap between rollers, angle of supply and discharge, diameter and geometry of rollers, changes of moment and energy consumption, reliable performance. The practice requires testing the form and dimensions of products in order to use these data in practice. It was found out that the formation of the test layer with minimal compaction and retaining properties, preserving the shape, only functions with gradual rolling of the cylindrically shaped rollers. All these data currently require new results, as there have been changes in the components, the properties of the components and the recipe. (Wyrwisz et al., 2013)

On the basis of the approaches developed to describe the process of the injection test in the roller gap, we used the hydrodynamic theory of pseudo-plastic fluid. This allows us to establish quantitative relations between the geometric characteristics of the working space (gap) and material properties and processing conditions (Андреев, 1975; Пеленко and Арет, 2008). When applying this theory of the process, we received a number of formulas that allow us to determine the pressure in the roller gap, based on the parameters and viscosity of the medium. Similar data dependencies can be used to process a discharge roller in case of back pressure in the Plenum chamber – a dough dividing machine.

All these data and their methods enable to organize research data, to identify and create goals and objective calculation. In all approaches to calculation, parameters are the same. Inability to determine the influence of the geometric dimensions of the working bodies (rollers), camera and rheology indicators for energy consumption in establishing the process of formation in machines of this class is a common drawback of these methods. On this basis, the main purpose of this work is to develop a useful method for determination of the specific power based on the torque and pressure in the roller gap when accounting for the rheological parameters.

Research methodology and discussion of results

It is believed that the rolling process starts from the moment when the material is between the rollers. Figure 1 presents the pattern of change in the thickness of the layer of raw material during rolling between the rollers. When rolling the cylindrically shaped rollers, the thickness of raw material is constantly changing in the middle part of the reservoir, i.e. in the area of capture. The same thickness is at the exit of the rollers. All cycles of the rolling curved the surface rollers without changing the gap of the middle part of the rollers from capture to capture. This allows the compression and shear test of the molding rollers during rolling. In order to obtain a layer of raw material with uniform thickness, rollers should be smoothly operated from the center of raw material. Obtaining the smoothness of rolling depends on the method of rolling the rollers on the material. Rollers of the same diameter rotating at the same angular velocity ω of radius R and length L Rollers have the same diameter and rotate at the same angular velocity ω of radius R and length L. Gaps between h_s and h_0 constitute the working surface of the rollers where, h_s is the distance between the roller surfaces during the test; h_0 is the minimum gap between the rollers.

The legend (Fig.1): h_1, h – half gap at the exit of the test and the variable gap; x_1, x is the corresponding abscissa; Xs – abscissa indicating the amount of the loaded test; hs is the thickness of the layer; Δh is the relative compression test in the gap of the rollers; $P_{\max}$ – the specific pressure on the roller test; P is the force between the rollers; M - torque; N_{cor} – net power.

Denoted by $U(x, y)$ is the corresponding velocity along OX axis through the V – velocity component along the axis OY. The overall objective of the hydrodynamics of a viscous incompressible fluid is reduced to solving a system of differential equations which include the continuity equation, equation of motion, equation of energy, rheological equation.

To define the process of rolling the dough, the authors (Андреев, 1975) introduced the following assumptions: the process is installed, insulated, material is not compressed and adhered to the surface of the rolls. This allowed the main equation to take the form:

$$\frac{dU}{dy}+\frac{dV}{dy}=0\ ,\quad \frac{d\tau}{dy}=\frac{dP}{dx}\ ,\quad \tau=\mu\cdot\frac{dU}{dy}\left|\frac{dU}{dy}\right|^{m-1} \tag{1}$$

where:

m is the index of the current. The last equation is a module of a power law of Ostwald in which the sign of the shear stresses corresponds to the sign of the shear rate. Boundary conditions for solving equations:

- if $u = 0$, $V = 0$, (symmetry of the flow),
- when $y = h$, $U = \omega\cdot R$; (no-slip condition test on the rolls),
- when $x = x1$, $G = 0$,
- when $x = xs$, $G = 0$.

The result is a total net moment of resistance M (N·m) and takes the following form:

$$M = \mu\left(\frac{2m+1}{m}\right)^m \cdot \omega^{m} R^m \cdot L \int_{-x_1}^{x_s} \frac{(h_1 - h)\cdot|h_1 - h|^{m-1}}{h^{2m+1}} \cdot dx \tag{2}$$

Net power:

$$N_{кор} = M_{заг} \cdot \omega \tag{3}$$

Test results for rotational rolls for solid bodies in the constant flow were used for calculations

The test of the effectiveness of solid bodies flow was carried out to calculate the rotation speed. Rheological constants – the index of the current m: $0.1 \leq m \leq 0.8$ and the viscosity μ=420Pa denote half the hs gaps at the inlet and h_1 at the outlet of the test, x-and h-current coordinates of a point on the roll (Fig.1).

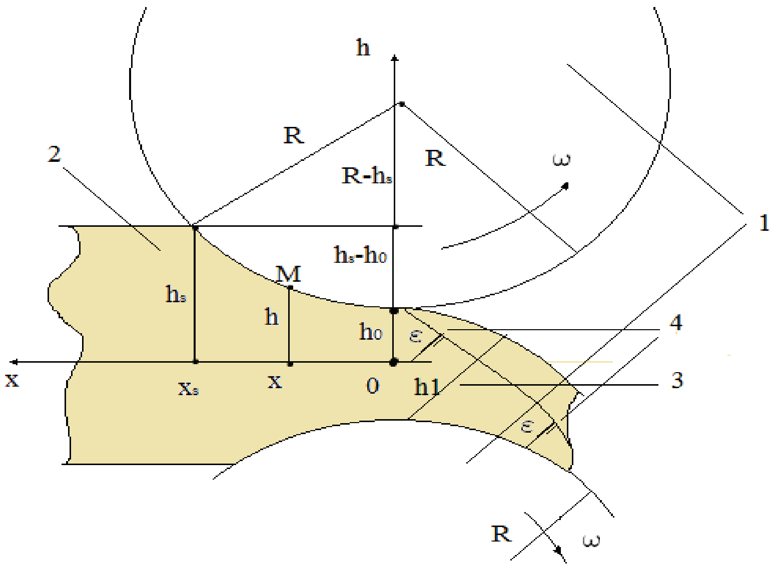

Figure 1. Profile of the rolling of t dough between the rollers. 1 – rotating rollers of radius R, half the distance between which h_0; 2 – thread test of half-thickness h_s at the inlet of the working chamber; 3 – roll out dough after passing through the rolls; 4 – predicted cracks and cracking of rolled out the stream below the critical thickness ε.

The predicted cracks and cracking of the rolled thread is below the critical thickness ε and refers to the lack of ability of this test to achieve the assumed result. The expression (Андреев 1976) in practice cannot be calculated numerically, since it contains an improper integral of the second kind with the singularity at the point x=0. Therefore, for thorough examination of the problem, research on the rotational properties of rollers should be carried out based on the geometry of construction presented in figure 1. According to the construction of the interaction surface of the rollers with dough, we have determined the parameter x (from 0 to the current point) and differential change (4, 5).

$$x = \sqrt{\frac{(h - h_0)R}{2}} \tag{4}$$

$$dx = \frac{\sqrt{2}}{4} \cdot \sqrt{\frac{R}{h - h_0}} \cdot dx \tag{5}$$

Moreover, empirical determination of the thickness of the dough that comes out from under the roller should take into account differences of a solid layer. On the basis of these studies, without loss of generality, this value is assumed as ε = 0.001.

Thus a useful moment of resistance of M rolls will be computed as a functional dependence of the half of the thickness of the layer of dough at the input of h_s and half of the gap between the rollers at the output of h_1. On the basis of certain parameters, and interactions of the rollers with the dough we compute the defining moments of acting in the first minutes of interaction between M_1 and the moment after the release of M_2 from the rollers. A useful point would be: M_{SAG}=M1+M2. Using the program (Mathcad-14) we will carry out the calculation according to our data:

Listing 1. (Fig. 2)

$$R := 0.16 \quad \omega := 2 \quad h1 := 0.01 \quad h0 := 0.001$$

$$\mu := 420 \quad \rho := 1.2 \cdot 10^{3} \quad \varepsilon := 0.001 \quad m := 0.3$$

$$L := 0.6 \quad hs := 0.1 \quad xs := \sqrt{\frac{(hs - h0) \cdot R}{2}} \quad x1 := \sqrt{\frac{(h1 - h0) \cdot R}{2}}$$

$$i := 0 .. 9 \quad HS_i := hs \cdot (1 + i) \quad j := 0 .. 9 \quad H1_j := h1 \cdot (1 + j)$$

$$M1_i := \frac{\sqrt{2}}{4} \cdot \frac{\mu}{\rho} \cdot \left(\frac{2m + 1}{m}\right)^{m} \omega^{m} \cdot R^{m} \cdot L \cdot \int_{\varepsilon}^{HS_i} \frac{(h1 - h) \cdot (|h1 - h|)^{m-1}}{h^{2m+1}} \cdot \frac{R}{\sqrt{(h - h0) \cdot R}} \, dh$$

$$M2_j := \frac{\sqrt{2}}{4} \cdot \frac{\mu}{\rho} \cdot \left(\frac{2m + 1}{m}\right)^{m} \omega^{m} \cdot R^{m} \cdot L \cdot \int_{-H1_j}^{-\varepsilon} \frac{(h1 - h) \cdot (|h1 - h|)^{m-1}}{(|h|)^{2m+1}} \cdot \frac{R}{\sqrt{|h - h0| \cdot R}} \, dh$$

Figure 2. Dialog box calculation program

After receiving the last equation you can calculate the net power N = (M1 + M2)·ω, and the specific pressure on the roller . The assay was performed at the constant value of viscosity = 0.3. Graphics useful power N (hs, h1) and specific pressure P (hs, h1) on the rollers (Fig. 3) was obtained.

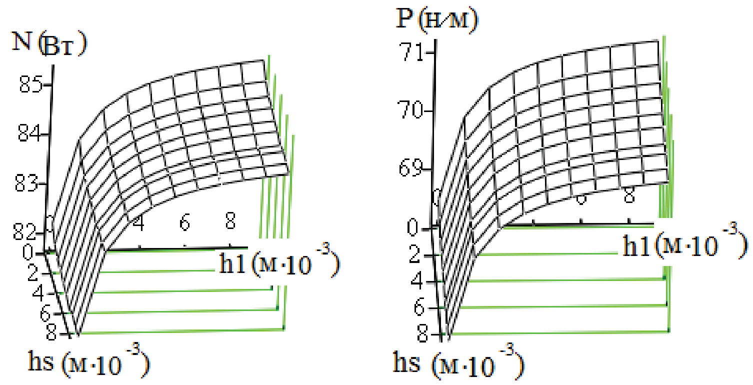

Figure 3. Graphics surface dependency of the net power N and the specific pressure P on the roller from a half-clearance on the hs entrance and exit test h1 for m = 0.3.

Note that increasing the value of the flow index m to a value of 0.75, graphics of both dependencies N and P have essentially the same character relative to the size of the input layer on the hs entrance (Fig.4). The difference lies in the increase of the net power and specific pressure. See how clearly the structural state of the dough that is rolled affects the capacity increase 1.5 times and increases the specific pressure at 3.2 times in compliance with the same geometrical parameters of the process.

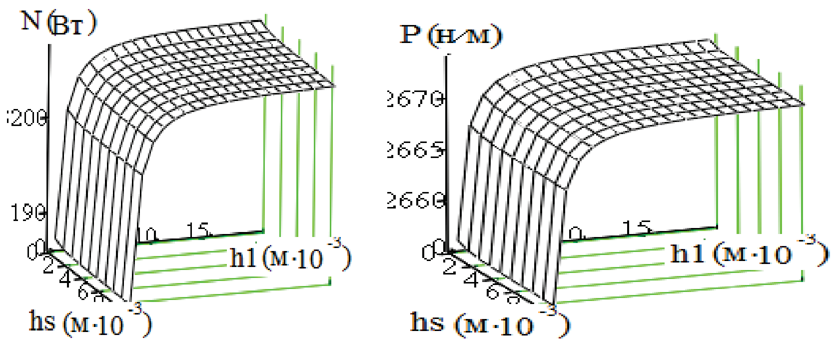

Figure 4. Graphs of surfaces dependency net power N and the specific pressure P on the roller from a half-clearance on the h_s entrance and exit test h1 for m = 0.75.

Based on the experimental research which was carried out, the obtained results were analysed based on the statistical tests. The least squares method was used for the analysis of the results. This method allowed for removal of polynomial regression curves. Using the tools of mathematical statistics, on the basis of the data of the conducted experimental results, the equation was used to model dependencies N(kW) and P(kN·m^{-1}), with $0.1 \leq m \leq 0.8$ of the second and third order. They provide the necessary accuracy of the approximation parameter ε the absence of rupture of the solid layer at the exit of the sheeting. Thus we have:

1. For ε = 0.001;

$$N31(m) = -0.82 + 10.9m - 38.1m^2 + 41.4m^3;$$

$$N21(m) = 1.2 - 10.4m + 17.7m^2;$$

$$P31(m) = -0.7 + 9.1m - 31.8m^2 + 34.5m^3;$$

$$P21(m) = 1.0 - 8.7m + 14.8m^2.$$

2. For ε = 0.002;

$$N32(m) = - 0.07 + 1.1m - 3.8m^2 + 4.4m^3;$$

$$N22(m) = 0.1 - 1.2m + 2.2m^2;$$

$$P32(m) = -0.06 + 0.9m - 3.1m^2 + 3.7m^3;$$

$$P22(m) = 0.1- 1.0m +1.8m^2.$$

3. For ε = 0.003;

$$N33(m) = -0.02 + 0.3m - 1.2m^2 + 1.5m^3;$$

$$N23(m) = 0.05 - 0.4m + 0.8m^2;$$

$$P33(m) = -0.01 + 0.3m - 1.0m^2 + 1.2m^3;$$

$$P23(m) = 0.04 - 0.3m + 0.7m^2.$$

4.For ε = 0.004;

$$N34(m) = - 0.01 + 0.1m - 0.5m^2 + 0.6m^3;$$

$$N24(m) = 0.02 - 0.2m + 0.4m^2;$$

$$P34(m) = 0.1m - 0.4m^2 + 0.5m^3;$$

$$P24(m) = 0.02 - 0.2m + 0.3m^3.$$

Summary

The use of this approach allows us to determine the overall quality of the rolled layer of dough. Analysis of the experimental results enabled the conclusion that rheological parameters are the main characteristics of machines that ensure a necessary and stable shape and dimensions of the product. The rheological indicators plow test give a rational approach to the decision of performing a rolling process. At the same time they contribute to the objective quality control methods and scientifically validated modes for the design of the rollers and the working chambers. The proposed method allows not only obtaining a specific pressure, but also determination of the optimal shape of the gap in which the pressure gradient is constant.

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WYZNACZANIE MOCY UŻYTECZNEJ I WPŁYW NA PARAMETRY REOLOGICZNE SUROWCÓW PODCZAS WALCOWANIA

Streszczenie. W artykule przedstawiono modelowanie matematyczne wyznaczania mocy użytecznej podczas walcowania surowców w szczelinie rolek obrotowych z uwzględnieniem parametrów reologicznych produktu końcowego. Wyznaczenie tych parametrów pozwoli na zmniejszenie zużycia energii, zwiększenie wydajności oraz zmniejszenie strat surowców w czasie produkcji. Zastosowanie tego rozwiązania zaproponowanego w artykule pozwala na określenie ogólnej jakości zwiniętej warstwy produktu. Analiza wyników eksperymentalnych pozwoliła stwierdzić, że główne cechy maszyny, zapewniają niezbędny stabilny kształt produktów i zapewniają dobre parametry reologiczne tych produktów. Testowanie wskaźników reologicznych pozwalają na racjonalne podejście do decyzji o prowadzeniu procesu walcowania. Jednocześnie poprawią sposoby kontroli jakości i będą miały wpływ na parametry konstrukcji trybów rolek i komór roboczych. Proponowany sposób nie tylko pozwala na uzyskanie określonego ciśnienia, a również pozwolą na określenie optymalnego kształtu szczeliny, w którym gradient ciśnienia jest stały.

Słowa kluczowe: surowce, hydrodynamika, rolowanie, parametry energetyczne, parametry reologiczne